

Brane Q-ball, branonium and brane inflation

Tomohiro Matsuda ¹

*Laboratory of Physics, Saitama Institute of Technology,
Fusaiji, Okabe-machi, Saitama 369-0293, Japan*

Abstract

We study the stability of branonium. Contrary to the previous arguments, global structure of branonium is not stable against spatial fluctuations. We show that branonium decays into local objects, which looks like Q-balls in the effective action. Therefore, we consider the idea of brane Q-balls in this paper. Brane Q-balls are produced as the remnants of unstable branonium. Although the brane Q-balls are conceptually different from the conventional Q-balls, they look similar in some parametric regions. We show how to distinguish brane Q-balls from conventional Q-balls.

¹matsuda@sit.ac.jp

1 Introduction

The most promising scenario of unified theory will be included in string theory, where the consistency is ensured by the requirement of additional dimensions and supersymmetry. Because of supersymmetry, many flat directions appear in the effective Lagrangian. Some flat directions parameterize the compactified space of the string theory, or the distances between branes. Brane distances play important roles in our arguments.² In this paper, we examine the stability of branonium[6]. Contrary to the previous arguments,³ branonium is not stable against spatial fluctuations and decays into local objects. In this paper, we advocate a new idea of brane Q-balls. The brane Q-balls are produced as the remnants of unstable branonium. Although the brane Q-balls are conceptually different from the conventional Q-balls, they look similar in some parametric regions. In this paper, we show why it is possible to distinguish the brane Q-balls from the conventional Q-balls. When the charge of the brane Q-ball exceeds a critical value, its decay is dominated by the radiation into the bulk.

2 Stability of branonium and brane Q-balls

In generic cases, branes have moduli, which allow relative motion in the bulk. When considering the cosmology induced by such situation, non-static configuration of these branes is therefore an interesting generic feature which deserves systematic study[3, 5, 8, 9, 10, 11]. “Branonium” is essentially the dynamics of a light IIA or IIB anti Dp -brane in the background of a heavy Dp -brane. For the case of D6-branes, it was shown[6] that the effective world volume action in such background has rather unusual properties. Their conclusion in ref.[6] was that the fully relativistic, non-linear action allows for the existence

²The idea of large extra dimension may solve or weaken the hierarchy problem[1], and the most natural embeddings of this picture in the string theory context would be realized by the brane construction. Inflation with a low fundamental scale ($M_* \ll M_p$) is discussed in ref.[2, 3]. Baryogenesis with a low fundamental scale is discussed in [4] and [5].

³In ref.[7] it is discussed that the orbital motion of a light anti D6-brane, taking account of possible time-variations in the background moduli fields, the Coulomb-like central potential arising through brane-antibrane interactions is modified to include time-dependent prefactors, which generally preclude the existence of stable elliptical orbits.

of non-precessing, elliptical orbits for the D6 anti-brane similar to those admitted for a non-relativistic particle experiencing a central potential. The stability of these orbits against fluctuations and radiation emission was also computed in ref.[6]. The conclusion was that both effects could be minimized at large distances. This planetary system of branes was named branonium.

On the other hand, in the usual arguments for the cosmological formation of Q-balls, it is well known that tiny spatial fluctuation effectively grows, which allows efficient formation of the Q-balls from the almost homogeneous initial state[13].

Obviously, the effective action of branonium looks similar to the one that was used for the discussion about the efficient formation of the Q-balls. Then a naive question arises. “Why branonium is stable? Doesn’t it fragment into local structure like Q-balls, as was discussed in the conventional arguments?” The purpose of this paper is to show why these two possibilities (branonium and Q-ball) are contradicting each other. Our conclusion is that branonium is not stable against spatial fluctuations, but decays into local structures that look like Q-balls in the effective action. The remnants of branonium look similar to the conventional Q-balls, which we call “brane Q-balls”. In spite of its name, the brane Q-ball is conceptually different from the conventional Q-ball.

In the discussion about the stability of branonium[6], the angular momentum l of a brane in motion is assumed to be a homogeneous parameter of the Universe. On the other hand, in the discussions about the formation of the conventional Q-balls, the angular velocity ω is assumed to be the homogeneous parameter. Obviously, these two different assumptions lead to distinctive results. The latter assumption seems quite appropriate if one wants to discuss the growth of the spatial fluctuation, as was discussed in ref.[12, 13, 14].⁴ On the other hand, if one uses the former assumption, the fluctuation of the brane distance induces the spatial gradient in ω .⁵ Then the former assumption leads

⁴Here the angular momentum of branonium corresponds to the charge density of the conventional Q-ball.

⁵Imagine a pair of oppositely charged strings rotating around each other. Because of the conservation of the angular momentum, some parts will bulge but other parts will dwindle. In this case, the angular momentum cannot be homogeneous because the fluctuation of the angular velocity (or the fluctuation of the distance) induces the movement of the angular momentum. As a result, the angular velocity becomes approximately the homogeneous parameter of the system, while the angular momentum fragments, as

to the structure of the unnatural local windings that cost huge energy when the spatial fluctuation grows. As a result, one might conclude that the branonium is stable against spatial fluctuations, because it costs huge energy for the spatial fluctuations to grow. In this case, however, it is à priori impossible to examine the spatial fragmentation of l . Thus in this case, the traditional arguments are trustworthy when one wants to examine the stability of the branonium-like structure.

Here we consider another question. In ref.[6], the non-perturbative brane decay à la Callan-Maldacena[15] is discussed to be interpreted as the sphaleron associated to the decay of the brane-antibrane system. The conclusion in ref.[6] was that the nucleation probability of the sphaleron is exponentially suppressed and negligible. If such suppression is effective, nucleation rate of the true vacuum is so small that branonium cannot decay into brane Q-balls. Is this argument really true in realistic cases? Our answer is negative to the conclusion in ref.[6]. It is already well known that the conventional sphalerons in the standard model are actually activated in the domain of the small (or vanishing) Higgs expectation value, while the sphaleron transition is suppressed in the vacuum of the large Higgs vev. In the domain of the vanishing Higgs vev, where the sphalerons become “massless”, the energy barrier does not make sense. In our case, the Higgs field in the conventional sphaleron model is corresponding to the distance between branes. If the spatial fluctuation of the distance grows, the distance finally becomes negligible in a local domain. Thus, one can easily understand why the Callan-Maldacena sphalerons are activated.

According to the above arguments, it is natural to think that the brane Q-ball, which is induced by a brane rotating at a distant around source branes, is a more generic cosmological configuration than branonium. In the effective action, the angular momentum l for the configuration of branonium is corresponding to the charge of the Q-ball. The assumption of the homogeneous l is not reliable, because the effective Lagrangian is essentially the same as the ones that were used for the discussion about the conventional Q-balls[13], in which the rapid formation of the Q-balls is confirmed. Our considerations are traditional in the arguments about the Q-balls, where the angular velocity ω is assumed to be

was discussed for conventional Q-balls.

the homogeneous constant.⁶

Although the effective action for the brane Q-ball looks similar to the one for the conventional Q-balls, it is natural to expect that some distinctive features will appear in the regions where the brane dynamics becomes effective. In the followings, we examine if there are crucial discrepancies between them.

First, we consider the core structure of a large Q-ball. In the core, the scalar field φ that forms the Q-ball develops large expectation value along a flat direction[16, 17]. In our case, as it can be seen from the effective Lagrangian, the brane distance δ_{brane} is corresponding to the scalar field φ for the conventional Q-ball. For the brane Q-ball, we define the scalar field $|\phi| \equiv \delta_{brane} M_*^2$, where M_* denotes the fundamental scale. The rotation is defined by $\phi = |\phi| e^{i\omega t}$.⁷ It is easy to see that the potential becomes flat in the core, where branes are placed at a distance. In this region, our arguments are not different from the ones for the conventional Q-balls.⁸ Since the potential is nearly flat in the core, we can consider the situation $\omega^2 \gg m_\phi^2$, where m_ϕ denotes the effective mass of the scalar field ϕ . Here we consider the most familiar example, the effective action for the parallel N coincident source BPS D3-branes and a rotating anti-D3-brane with d large extra dimensions.⁹ Since we are considering the brane Q-ball that might have been

⁶Here we define ω so that it is consistent with the definition of l in ref.[6].

⁷In this paper, we assume that the direction of the rotational axis is homogeneous even if d (the number of the extra dimensions perpendicular to the rotating brane) exceeds 2. We think further discussions about the inhomogeneous rotational axis are useful and interesting for the quantitative discussions about $d > 2$ models. However, such analyses require numerical methods, and are obviously beyond the scope of this paper. Although the quantitative discussions will be much more difficult than the conventional ones, the qualitative results will be consistent with the $d = 2$ cases.

⁸Here we assume that the conventional Q-balls are induced by the flat directions of the Minimal Supersymmetric Standard Model(MSSM)[12].

⁹Although we are considering D3-branes in this paragraph, it is important to note about brane Q-balls constructed from higher-dimensional branes. As our discussions about brane Q-balls are based on the effective action of such brane configurations, the “dimensionality” should be found in the effective action. Therefore we can focus our attention to the dimensionality of the brane configuration that appears in the effective action, because discussions about Q-balls are based on the effective action. Obviously, the potential of the brane distance ϕ depends on the dimensionality of the branes. However, the precise form of the potential is not relevant for the actual discussion about Q-balls, since the only requirement that is used to discuss the properties of “fat” Q-balls is the flatness of the potential at large ϕ . The parameters

produced after brane inflation, it is useful to consider the same situation as the model for brane inflation[8]. In our simplest example, the effective action is described by;

$$S \simeq -T_3 \int d^4\zeta \frac{1}{2} \partial^\mu X_a \partial_\mu X_a + \dots, \quad (2.1)$$

where X_a denotes the transverse coordinates of the brane, which represents the relative distance if one assumes approximate spherical symmetry. Then one can obtain the kinetic term for the field ϕ ,

$$\begin{aligned} S &\simeq -T_3 \int d^4\zeta \frac{1}{2} \partial^\mu X_a \partial_\mu X_a \\ &\equiv - \int d^4\zeta \frac{1}{2} \partial^\mu \phi \partial_\mu \phi. \end{aligned} \quad (2.2)$$

If the two branes are separated at a distance, the potential for the normalized field $|\phi| = \sqrt{T_3} \delta_{brane}$ is given by[8]

$$V(\phi) = M_*^4 \left[1 - \frac{k M_*^4}{\phi^4} \right], \quad (2.3)$$

where $M_*^4 \simeq T_{D3}$ is assumed, and k is a constant of $k < O(10^{-3})$. Since the potential (2.3) is flat for $\delta_{brane} \gg M_*^{-1}$, the situation in the core is quite similar to the usual Q-ball configurations with the flat directions[16].

of the “fat” Q-balls do not depend on the precise form of the potential, as we will discuss in the later paragraph.

On the other hand, we need more discussions about the kinetic term of the scalar field ϕ . Here we define the coordinates of the compactified and uncompactified space as x^μ and x^a , respectively. Naively one might think that the kinetic term of the scalar field ϕ contains differentials of the form $f(\partial\phi/\partial x^a, \dots)$, where f is a function of $\partial\phi/\partial x^a$ and other differentials and fields, so that the discussion of the Q-balls must depend on the dimensionality of the original branes. However, as was noted in ref.[11], the effect of compactification is significant for such cosmological fluctuations. Since the compactification radius must be small compared to the horizon size during inflation, any variation of a field in the compactified direction is suppressed. In our case, the length scale of the fluctuation of the scalar field ϕ is much larger than the compactification radius. Therefore the scalar field ϕ is constant in the compactified directions, which makes our discussions about the dimensionality of brane Q-balls much simpler than expected. As a result, as far as the effective action is concerned, the characteristic features of brane Q-balls do not depend on the dimensionality of the original brane configuration(branonium), except for the bulk radiation that will be discussed later in this paper. Therefore it is important to note that we are not considering D3-branes as a very special example, but as a minimal configuration that represents the generic feature of such configurations.

To calculate the physical parameters for the brane Q-balls, we review the discussion about the conventional fat Q-balls[16], which are fat in a sense that the effective mass m_ϕ in the core is much smaller than the one in the true vacuum. If the supersymmetry breaking in the true vacuum is induced by the gauge mediation, flat directions of MSSM are naturally the candidates of such fat Q-balls. The fat Q-balls has two distinctive regions. In the core of the Q-ball, where the potential is flat, the term $\sim \omega^2 \phi^2$ dominates the potential. In this region the configuration becomes thick, which constitutes the fat core. Since the volume scales as the third power of the radius while the surface area scales as the second power, its core rather than its surface dominates the energy of the fat Q-ball. The fat Q-ball has the following properties[17]

$$\begin{aligned} r_Q &\simeq \frac{Q^{1/4}}{M_*}, & \omega &\simeq \frac{M_*}{Q^{1/4}} \\ \phi_Q &\simeq M_* Q^{1/4}, & E_Q &\simeq M_* Q^{3/4} \end{aligned} \quad (2.4)$$

where Q , r_Q , and E_Q denote the charge, the radius, and the energy of the Q-ball. Here ϕ_Q denotes the vacuum expectation value of ϕ in the core. In the core, the brane Q-balls look quite similar to the conventional Q-balls.

Second, we examine the surface of the brane Q-balls. Conventional fat Q-balls have the thin-wall regime, which interpolates between the fat core and the outer space of the true vacuum. The potential is no more flat in this surface region, since the gauge mediation of the supersymmetry breaking becomes effective. In our model, similar to the conventional fat Q-balls, the brane distance gradually becomes shorter toward the surface region. At the same time, the effective potential for the field ϕ becomes steeper because of the tachyonic instability. In the surface region where the effective mass m_ϕ exceeds $|\omega|$, the approximation of the flat potential fails. Because ω^2 is much smaller than m_ϕ^2 in this region, one can ignore the time dependence and construct the steep boundary configuration of the curved brane. The boundary configuration looks similar to the conventional sphalerons. Such a solution is already constructed in ref.[15].¹⁰ Here we do not repeat the arguments, since the exact solution is not needed in our case. In ref. [15, 18], it is shown that the decaying brane solution diverges at a critical radius. If the configuration crosses the divergence in the surface of the brane Q-ball, the surface

¹⁰See also ref.[18].

effect will dominate. On the other hand, if the radius of the brane Q-ball is so large that the surface configuration does not induce such divergence, one can safely use the fat core approximation. For the effective potential (2.3), the surface region appears where the field ϕ becomes smaller than $\phi_{surface} = k^{1/6}Q^{1/12}M_*$. In this region, the curved brane configuration is described by the sphaleron-like configuration in ref.[15, 18]. In ref.[15] and [18], the effective action for a Dp-brane in the flat target space with a nontrivial background is written, and the equation of motion is obtained for the transverse coordinate X .¹¹ For us, the important characteristics of these solutions are the divergence of $\partial_\mu X$ that appears at the critical radius r_c .¹² Although we will not review the explicit calculations in ref.[15], it is easy to understand that the divergences are inevitable in generic situations if the nontrivial backgrounds are included. Thus, if the surface configuration of our brane Q-ball is crossing the critical radius, the characteristics of the brane Q-ball will be determined by the surface, not by the fat core. According to ref.[15, 18], one can see that the critical radius is physically at $r_c \simeq \delta_{brane}$. In our model, δ_{brane} in the above condition is the distance where the surface region starts. Thus, the critical radius is $r_c \simeq k^{1/6}Q^{1/12}M_*^{-1}$ in our model.¹³ As a result, the properties given in (2.4) are plausible only when the brane Q-balls satisfy the condition $r_Q \gg r_c$. Obviously, the above requirement is satisfied in our model. There is no divergence in the surface region of the brane Q-ball. The brane Q-balls look similar to the conventional fat Q-balls, in a sense that their properties are given by eq.(2.4).

Third, we examine the decay channel of the brane Q-balls. We show that the obvious distinction appears when the brane Q-ball exceeds the critical charge. In general, when one considers the time-dependent brane configurations, one cannot ignore the radiation into the bulk. The radiation into the bulk is proportional to a_b^2 , where a_b is the acceleration of the brane in motion in the bulk[6]. We examine if this peculiar effect of the brane dynamics can exceed the conventional decay mode of the Q-balls. The power radiated

¹¹The equation of motion is given by eq.(3.6) in ref.[15], or by eq.(2.11) in ref.[18]. Then the solution is given by eq.(3.9) and (3.10) in ref.[15], or by eq.(2.13) in ref.[18].

¹²The critical radius r_c is given by the form $r_c \equiv (B^2 - A^2)^{1/(2p-2)}$ in ref.[15], and $r_c \equiv |p/2f|$ in ref.[18].

¹³Of course, in the fat core of the brane Q-ball, the actual brane distance is different from δ_{brane} in the above condition. δ_{brane} in the above condition is the brane distance where the surface region starts.

into the bulk, $P = -\frac{dE_Q}{dt}$, is given by[6]

$$P \sim \frac{1}{8\pi} (\kappa_4 T_p V_p)^2 a_b^2, \quad (2.5)$$

where κ_4 and V_p are the 4-dimensional gravitational coupling and the spatial volume of the Dp-brane, respectively. Here we consider the local structure of the D3-brane. The volume V_p is given by the volume of the D3 brane Q-ball, $V_3 \simeq 4\pi r_Q^3/3$. We also assume the conventional form of the brane tension, $T_{Dp} \simeq M_*^p$. On the other hand, the usual decay of the conventional Q-balls through charged massless fermions has been studied in ref.[14], where an upper bound is given by

$$|\frac{dQ}{dt}| \leq \frac{\omega^3 A}{192\pi^2}. \quad (2.6)$$

Here $A = 4\pi r_Q^2$ is the surface area of the Q-ball. From eq.(2.6) and (2.4), we obtain the upper bound

$$\frac{dE_Q}{dt} \leq -c_q \frac{M_*^2}{Q^{1/2}}, \quad (2.7)$$

where the constant c_q is $c_q \leq O(10^{-3})$. From eq.(2.4), (2.5) and (2.7), it is easy to see that the radiation into bulk dominates when the charge Q exceeds the critical value

$$Q_c^{3/2} \simeq c_1 \frac{M_p^2}{M_*^2}, \quad (2.8)$$

where $c_1 \simeq 10^{-2}$. Here the approximation $a_b \simeq \delta_{brane} \omega^2 \simeq (\phi_Q/M_*^2) \omega^2$ is used.

The above results suggest that the brane Q-balls look similar to the conventional Q-ball if it is in some parametric regions, however a crucial difference appears when the charge exceeds the critical value.

Fourth, we consider the effect of the Hubble parameter. In the followings, we show why the Hubble parameter is important for the discussions about the stability of branonium. As was discussed in ref.[19], the effect of the Hubble parameter is not negligible in the discussions about the conventional Q-balls. On the other hand, in the previous discussions about branonium, a special limit is considered and the Hubble parameter is neglected. If the Hubble parameter is effective, the global structure of branonium is nothing but the model for brane inflation with the initial rotational motion[19]. Let us consider a conventional example where the time dependence of the energy density ρ is given by the fluid equation $\dot{\rho} = -3\frac{\dot{a}}{a}(\rho + P)$, where P denotes the pressure of the Universe. Adopting

the general expressions for the energy density and pressure of a homogeneous scalar field ϕ , one can easily obtain the equation

$$\ddot{\phi} + 3H\dot{\phi} = -\frac{dV}{d\phi} \quad (2.9)$$

where H is the Hubble parameter, which is given by the formula

$$H^2 = \frac{1}{3M_p^2} \left[V(\phi) + \frac{1}{2}\dot{\phi}^2 \right]. \quad (2.10)$$

If one wants to assume that the discussion in [6] is valid, one should consider the following two constraints. First, the field ϕ must violate the slow-roll condition, which means $|V''(\phi)| \gg H^2$. Otherwise, the configuration of branonium induces rapid expansion. Here we have assumed that the Hubble parameter is $H^2 \simeq M_*^4/M_p^2$ [8], as in the cases for the generic situations. The above condition puts an upper bound for ϕ . In the case of D3-branes, the explicit form of the condition becomes

$$\phi \ll k^{1/6} M_* \times \left(\frac{M_p}{M_*} \right)^{1/3}. \quad (2.11)$$

According to ref.[19] and the above arguments, the condition $r_Q \gg H^{-1}$ [19] is required for the stable configuration of branonium. This condition is necessary to ensure the homogeneity of l within the Hubble radius. However, if the above constraint for the homogeneous l is satisfied, it is hard to believe that the condition (2.11) is satisfied for the realistic values of $k < 1$ and $M_* < M_p$.

As a result, we conclude that the branonium configuration is a precedent state of the brane Q-balls or brane inflation. In this sense, branonium is not stable. Branonium can appear only in a short transient period of the early Universe.

3 Conclusions and Discussions

In this paper, we have examined the stability of branonium. Branonium is not stable, and decays into brane Q-balls. The new idea of the brane Q-ball is studied. The brane Q-ball looks similar to the conventional Q-ball when its charge is smaller than the critical value. If it exceeds the critical value, the brane Q-ball decays predominantly into the bulk, which is the most distinctive feature of the brane Q-ball.

4 Acknowledgment

We wish to thank K.Shima for encouragement, and our colleagues in Tokyo University for their kind hospitality.

References

- [1] I. Antoniadis, N. A-Hamed, S. Dimopoulos, and G. R. Dvali, *New dimensions at a millimeter to a fermi and superstrings at a TeV*, *Phys.Lett.B*436(1998)257 [hep-ph/9804398]; I. Antoniadis, *A possible new dimension at a few TeV*, *Phys.Lett.B*246(1990)377; N. A-Hamed, S. Dimopoulos and G. R. Dvali, *The hierarchy problem and new dimensions at a millimeter*, *Phys.Lett.B*429(1998)263 [hep-ph/9803315].
- [2] N. Arkani-Hamed, S. Dimopoulos, N. Kaloper, and J. March-Russell, *Rapid asymmetric inflation and early cosmology in theories with submillimeter dimensions*, *Nucl.Phys.B*567(2000)189 [hep-ph/9903224]; R. N. Mohapatra, A. Perez-Lorenzana, and C. A. de S. Pires, *Inflation in models with large extra dimensions driven by a bulk scalar field*, *Phys.Rev.D*62(2000)105030 [hep-ph/0003089]; A. M. Green and A. Mazumdar, *Dynamics of a large extra dimension inspired hybrid inflation model*, *Phys.Rev.D*65(2002)105022 [hep-ph/0201209]; D. H. Lyth, *Inflation with TeV scale gravity needs supersymmetry*, *Phys.Lett.B*448(1999)191 [hep-ph/9810320]; T. Matsuda, *Kaluza-Klein modes in hybrid inflation*, *Phys.Rev.D*66(2002)107301 [hep-ph/0209214]; T. Matsuda, *Successful D term inflation with moduli*, *Phys.Lett.B*423(1998)35 [hep-ph/9705448].
- [3] T. Matsuda, *F term, D term and hybrid brane inflation*, *JCAP* 0311(2003)003 [hep-ph/0302078] T. Matsuda, *Nontachyonic brane inflation*, *Phys.Rev.D*67(2003)083519 [hep-ph/0302035]; T. Matsuda, *Topological hybrid inflation in brane world*, *JCAP* 0306(2003)007 [hep-ph/0302204]; T. Matsuda, *Thermal hybrid inflation in brane world*, *Phys.Rev.D*68(2003)047702 [hep-ph/0302253].

- [4] G. R. Dvali, G. Gabadadze, *Nonconservation of global charges in the brane universe and baryogenesis*, *Phys.Lett.B*460(1999)47 [hep-ph/9904221]; A. Masiero, M. Peloso, L. Sorbo, and R. Tabbash, *Baryogenesis versus proton stability in theories with extra dimensions*, *Phys.Rev.D*62(2000)063515 [hep-ph/0003312]; A. Pilaftsis, *Leptogenesis in theories with large extra dimensions*, *Phys.Rev.D*60(1999)105023 [hep-ph/9906265]; R. Allahverdi, K. Enqvist, A. Mazumdar and A. Perez-Lorenzana, *Baryogenesis in theories with large extra spatial dimensions*, *Nucl.Phys.B*618(2001)377 [hep-ph/0108225]; S. Davidson, M. Losada, and A. Riotto, *A new perspective on baryogenesis*, *Phys.Rev.Lett.*84(2000)4284 [hep-ph/0001301]; T. Matsuda, *Hybridized Affleck-Dine baryogenesis*, *Phys.Rev.D*67(2003)127302 [hep-ph/0303132]; T. Matsuda, *Affleck-Dine baryogenesis after thermal brane inflation*, *Phys.Rev.D*65(2002)103501 [hep-ph/0202209]; T. Matsuda, *Affleck-Dine baryogenesis in the local domain*, *Phys.Rev.D*65(2002)103502 [hep-ph/0202211]; T. Matsuda, *Electroweak baryogenesis mediated by locally supersymmetry breaking defects*, *Phys.Rev.D*64(2001)083512 [hep-ph/0107314]; T. Matsuda, *Curvaton parindent can accommodate multiple low inflation scales*, *Class.Quant.Grav.*21(2004)L11 [hep-ph/0312058].
- [5] T. Matsuda, *Baryon number violation, baryogenesis and defects with extra dimensions*, *Phys.Rev.D*66(2002)023508 [hep-ph/0204307]; T. Matsuda, *Activated sphalerons and large extra dimensions*, *Phys.Rev.D*66(2002)047301 [hep-ph/0205331]; T. Matsuda, *Enhanced baryon number violation due to cosmological defects with localized fermions along extra dimensions*, *Phys.Rev.D*65(2002)107302 [hep-ph/0202258]; T. Matsuda, *Defect mediated electroweak baryogenesis and hierarchy*, *J.Phys.G*27(2001)L103 [hep-ph/0102040].
- [6] C. P. Burgess, P. Martineau, F. Queved and R. Rabadan, *Branonium*, *JHEP* 0306(2003)037[hep-th/0303170]; C. P. Burgess, P. Martineau, F. Queved and R. Rabadan, *D-brane chemistry*, *JHEP* 0401(2004)067[hep-th/0310010]; K. Takahashi and K. Ichikawa, *Cosmology and two body problem of D-branes*, *Phys.Rev.D*69(2004)103506[hep-th/0310142].
- [7] J. Ellison and A. Lukas, *The Stability of Branonium*[hep-th/0312110].

- [8] G. R. Dvali and S. H. Henry Tye *Brane inflation*, *Phys.Lett.B*450(1999)72 [hep-ph/9812483].
- [9] G. R. Dvali, I. I. Kogan and M. A. Shifman, *Topological effects in our brane world from extra dimensions*, *Phys.Rev.D*62(2000)106001 [hep-th/0006213].
- [10] T. Matsuda, *Incidental Brane Defects*, *JHEP* 0309(2003)064 [hep-th/0309266];
T.Matsuda, *Comment on the stability of the Yukawa couplings and the cosmological problems of interesting brane models*[hep-ph/0309314]
- [11] S. Sarangi, S. H. H. Tye, *Cosmic string production towards the end of brane inflation*, *Phys.Lett.B*536(2002)185 [hep-th/0204074]; N. Jones, H. Stoica, and S. H. H. Tye, *Brane interaction as the origin of inflation*, *JHEP* 0207(2002)051 [hep-th/0203163];
L. Pogosian, S. H. H. Tye, I. Wasserman and M. Wyman, *Observational constraints on cosmic string production during brane inflation*, *Phys.Rev.D*68(2003)023506 [hep-th/0304188]; M. Gomez-Reino and I. Zavala, *Recombination of intersecting D-branes and cosmological inflation*, *JHEP*0209(2002)020 [hep-th/0207278]; M. Majumdar and A. Christine-Davis, *Cosmological creation of D-branes and anti-D-branes*, *JHEP* 0203(2002)056 [hep-th/0202148]; T. Matsuda, *String production after angled brane inflation*, *Phys.Rev.D*70(2004)023502[hep-ph/0403092]; T. Matsuda, *Formation of cosmological brane defects*[hep-ph/0402232].
- [12] S. R. Coleman, *Q Balls*,*Nucl.Phys.B*262(1985)263; A. Kusenko, *Solitons in the supersymmetric extensions of the Standard Model*, *Phys.Lett.B*405(1997)108[hep-ph/9704273]; K. Enqvist, A. Mazumdar, *Cosmological consequences of MSSM flat directions*, *Phys.Rept.*380(2003)99.
- [13] S. Kasuya and M. Kawasaki, *Q-ball Formation through Affleck-Dine Mechanism*, *Phys.Rev.D*61(2000)041301[hep-ph/9909509].
- [14] A. G. Cohen, S. R. Coleman, H. Georgi and A. Manohar, *The evaporation of Q balls*, *Nucl.Phys.B*272(1986)301.
- [15] C. G. Callan and Jr., J. M. Maldacena, *Brane Dynamics From the Born-Infeld Action*, *Nucl.Phys.B*513(1998)198[hep-th/9708147].

- [16] G. R. Dvali, A. Kusenko, M. E. Shaposhnikov, *New physics in a nutshell, or Q-ball as a power plant*, *Phys.Lett.B*417(1998)99[hep-ph/9707423].
- [17] S. Kasuya, M. Kawasaki, *New type of stable Q balls in the gauge-mediated supersymmetry breaking*, *Phys.Rev.Lett.*85(2000)2677[hep-ph/0006128].
- [18] K. Hashimoto, *Dynamical Decay of Brane-Antibrane and Dielectric Brane*, *JHEP* 0207(2002)035[hep-th/0204203].
- [19] T. Matsuda, *Q ball inflation*, *Phys.Rev.D*68(2003)127302[hep-ph/0309339].